Arid Zone Journal of Engineering, Technology and Environment, December, 2018; Vol. 14(4): 670-677

Print ISSN: 1596-2490, Electronic ISSN: 2545-5818, www.azojete.com.ng

EVALUATION OF MECHANICAL PROPERTIES OF POLYMER-COMPOSITE REINFORCED WITH NIGERIAN LONG BAMBOO FIBRES

F. A. Ovat
(Department of Mechanical Engineering, Cross River University of Technology Calabar-Nigeria)
Corresponding Author's E-mail: fraijoe@yahoo.com

Abstract
Bamboo reinforced epoxy have adequate properties to attract its use as structural material in engineering applications. Research materials on bamboo-plastics composites are not common. This work is an experimental study of bamboo-epoxy composite on which mechanical properties were evaluated. The long bamboo fibres were extracted from Bambusa vulgaris. The production of the composite was carried out using Bisphenol-A-di glycidyl ether (BADGE) as the matrix and the long bamboo fibre as reinforcement. Tests were carried out to determine the mechanical properties such as flexural strengths and hardness. The flexural strength of the reinforced composite (145.71N/mm^2) is three times stronger than the non-reinforced composite. The hardness value was not significantly affected. The study indicated that the mechanical properties of bamboo-epoxy were comparable to ordinary fibre- glass reinforced plastics. Therefore, the material developed can be used in structural applications with a strong dependence on its mechanical properties.

Keywords: Bisphenol-A-di glycidyl ether, Natural fibre, Flexural strength, Hardness, Long bamboo fibre, Composite.

1. Introduction

Bamboo is an abundant natural resource in Asia, Africa (West Africa) and South America, and has been used traditionally for fabrication of village houses and home utensils, without fully exploiting its potential as a structural material. Massive use of bamboo in this direction appears possible if it is deployed as a reinforcing constituent in a composite material. Growing environmental awareness has triggered the researchers worldwide to develop and utilise materials that are compatible with the environment. In the process, natural fibres have become suitable alternatives to traditional synthetic or man-made fibres and have the potential to be used in cheaper, more sustainable and more environmentally friendly composite materials. Natural organic fibres can be derived from either animal or plant sources. The majority of useful natural textile fibres are plant-derived, with the exceptions of wool and silk. All plant fibres are composed of cellulose, whereas fibres of animal origin consist of proteins (INBAR, 2005).

The mechanical properties of a natural fibre-reinforced composite depend on many parameters such as fibre strength, modulus, fibre length, fibre orientation, in addition and fibre-matrix interfacial bond strength. A strong fibre-matrix interface bond is critical for high mechanical properties of composites. A good interfacial bond is required for effective stress transfer from the matrix to the fibre whereby maximum utilisation of the fibre strength in the composite is achieved (Karnani *et al.*, 1997).

Modification to the fibre also improves resistance to moisture induced degradation of the interface and the composite properties (Joseph *et al.*, 2000). In addition, factors like processing conditions/techniques have a significant influence on the mechanical properties of fibre reinforced composites (George *et al.*, 2001). Mechanical properties of natural fibres, especially flax, hemp, jute and sisal, are very good and may compete with glass fibre in specific strength and modulus (Van and Kiekens, 2002; Frederick and Norman, 2004).

A number of investigations have been conducted on several types of natural fibres such as kenaf, hemp, flax, bamboo, and jute to study the effect of these fibres on the mechanical properties of

composite materials (Satyanarayana *et al.*,, 1990; Gowda *et al.,* 1999). Mansur and Aziz 1983, studied bamboo-mesh reinforced cement composites and found that this reinforcing material could enhance the ductility and toughness of the cement matrix, and increased significantly its tensile, flexural, and impact strengths. On the other hand, jute fabric-reinforced polyester composites were tested for the evaluation of mechanical properties and compared with wood composite Gowda *et al.* (1999) and it was found that the jute fibre composite has better strengths than wood composites. A pulp fibre reinforced thermoplastic composite was investigated and found to have a combination of stiffness increased by a factor of 5.2 and strength increased by a factor of 2.3 compared to the virgin polymer (Lundquist *et al.*, 2003).

Joseph *et al.* 2002, tested banana fibre and glass fibre with varying fibre length and fibre content as well. Luo and Netravali 1999, studied the tensile and flexural properties of the green composites with different pineapple fibre content and compared with the virgin resin. Sisal fibre is fairly coarse and inflexible with good strength, durability, ability to stretch, affinity for certain dyestuffs and resistance to deterioration in seawater. Sisal ropes and twines are widely used for marine, agricultural, shipping and industrial use. Belmares *et al.*, 1983) found that sisal, henequen, and palm fibre have similar physical, chemical, and tensile properties. Casaurang *et al.* 1991, carried out a study on the properties of henequen fibre and found out that these fibres have mechanical properties suitable for reinforcing thermoplastic resins. Ahmed *et al.* 1999, carried out research work on filament wound cotton fibre reinforced for reinforcing high-density polyethylene (HDPE) resin. Khalid *et al.* 1998, studied the use of cotton fiber-reinforced epoxy composites along with glass-fiber-reinforced polymers. Fuad, Rahmad and Azlan (1998) investigated the new type of wood based filler derived from oil palm wood flour (OPWF) for bio-based thermoplastics composites by thermogravimetric analysis and the results are very promising.

Schneider and Karmaker, (1996) developed composites using jute and kenaf fibre and polypropylene resins and they reported that jute fibre provides better mechanical properties than kenaf fibre. Sreekala *et al.* 2000, performed one of the pioneering studies on the mechanical performance of treated oil palm fibre-reinforced composites. They studied the tensile stress-stain behaviour of composites having 40% by weight fibre loading. Isocyanate-silane-acrylate, latex coated and peroxide-treated composites withstood tensile stresses to higher strain level. Isocyanate treated, silane treated, acrylate, acetylated and latex coated composites showed yielding and high extensibility. The tensile modulus of the composites at 2% elongation showed slight enhancement upon mercerization and permanganate treatment. The elongation at break of the composites with chemically modified fibre was attributed to the changes in the chemical structure and bondability of the fibre. Alkali treated (5%) sisal-polyester biocomposite showed about 22% increases in tensile strength (Mishra *et al.*, 2002).

Ichazo *et al.*, (2001) found that adding silane treated wood flour to PP (polypropylene) produced a sustained increase in the tensile modulus and tensile strength of the composite. Joseph and Thomas (1993) studied the effect of chemical treatment on the tensile and dynamic mechanical properties of short sisal fibre reinforced low-density polyethylene composites. It was observed that the CTDIC (cardanol derivative of toluene diisocyanate) treatment reduced the hydrophilic nature of the sisal fibre and enhanced the tensile properties of the sisal-LDPE (Low-Density Polyethylene) composites. They found that peroxide and permanganate treated fibre-reinforced composites showed an enhancement in tensile properties. They concluded that with a suitable fibre surface treatment, the mechanical properties and dimensional stability of sisal-LDPE composites could be improved.

Natural fibre reinforced polymer composites are hybrid with their properties, with characteristics of both natural fibres and polymers. In the beginning of the 20th-century wood- or cotton fibre reinforced phenol- or melamine formaldehyde resins were fabricated and used in electrical

applications for their nonconductive and heat-resistant properties. Incorporation of natural fibres into the polymer is now a standard technology to improve the mechanical properties of the polymer. Mechanical properties like tensile strength and young's modulus are enhanced in the end products (composites) as the fibres in the composites determine the tensile strength and young's modulus of the materials (Joseph *et al.*, 1996).

One of the largest areas of recent growth in natural fibre plastic composites in worldwide is the automotive industry, where natural fibres are advantageously used as a result of their low density and increasing environmental pressures. Natural fibres composites found application where load bearing capacity and dimensional stability under moist and high thermal conditions are of second order importance. For example, flax fibre reinforced polyolefins are extensively used today in the automotive industry, but the fibre acts mainly as filler material in non-structural interior panels (Holbery and Houston, 2006; Tavman, 1997 and Yamamoto *et al.*, 2003).

2. Materials and Methods

The materials used here included but not limited to the following; Hydrogen peroxide, concentrated acetic acid, enamel bowl, oven, ladle, bamboo chips, weighing scale, water, plastic cup, bisphenol-A-di glycidyl ether, polyvinyl alcohol, brush, polsh (gel), metal bars of 300mm x 3mm, metal sheet, ceramic tile of 300mm x 200mm square area, weight of 8kg, thermometer, pH meter and a graduated cylinder.

2.1 Fibre Material

Fibre is the reinforcing phase of a composite material. Bamboo is available everywhere around the world and is an abundant natural resource. It has been a conventional construction material since ancient times. The scientific name of the type of bamboo used for this work is *Bambusa Vulgaris* (Valadez-Gonzales, Cervantes-Uc, Olayo and Herrera, 1999). This is one of the predominant species of bamboo in Nigeria, West Africa and the Western Ghats in India. This species occupies approximately 53% of the total bamboo area in India. Bamboo is an orthotropic material with high strength along and low strength transversal to its fibres. In the present work, long bamboo was used as the reinforcing material in all the composites. Blemish free bamboo columns were obtained from a typical Nigerian environment and were manually cut to chips of 25 mm in length. The moisture content of the bamboo was determined using the gravitational method and the average moisture was calculated to be 20.5%.

2.2 Matrix Material

Among different types of matrix materials, polymer matrices are the most commonly used because of cost efficiency, ease of fabricating complex parts with less tooling cost and they also have excellent room temperature properties when compared. Polymer matrices can be either thermoplastic or thermoset. The most commonly used thermoset resins are epoxy, vinyl ester, polyester and phenolics.

Among them, the epoxy resins are being widely used for many advanced composites due to their advantages such as excellent adhesion to wide variety of fibres, good performance at elevated temperatures and superior mechanical and electrical properties. In addition, to that, they have low shrinkage upon curing and good chemical resistance. Due to several advantages over other thermoset polymers as mentioned above, epoxy (LY 556) was chosen as the matrix material for the present research work. It chemically belongs to the ‘epoxide' family and its common name is Bisphenol-A-Diglycidyl-Ether (BADGE) or Diglycidyl ether Bisphenol- A- (DGEBA).

2.3 Composite Fabrication

There are several methods of fabricating composite, the method employed here was the hand lay-up method. A mould having dimensions of 300 x 300 x 3mm was used. Polyvinyl alcohol and wax were used to polish the surface of the mould, they both served as releasing agents that made it easy during demolding of the composite. The resin, Bisphenol-A-di glycidyl ether(BADGE) and the hardener were measured into a beaker in a ratio of 2:1, that is two parts of BADGE against one part of the hardener [DER (Dow Epoxy Resin)731]. The mixture was stirred with a glass rod.

Part of the resin was poured in the mould and a brush was used to distribute it across the surface of the mould. The fibres were manually distributed across the mould. The resin was added in the mould while the brush was used to impregnate the fibres until they were saturated. The cast was cured using a light weight of 8.72KN/.

The mould was closed for curing at a temperature of 25°C for 24 hours at constant pressure. The cast was cured again in the air for 24hours after removal from the mould. Samples were prepared according to ASTM standard for each mechanical parameter and then taken to the laboratory for test. Utmost care was taken to maintain uniformity and homogeneity of the composite since reproducibility is somewhat difficult in hand layup method that was used.

2.4 Flexural Test

The test sample was dimensioned to standard according to ASTM testing code ASTM D7264, (4mm thickness x 13mm width x with a length of 300mm. The sample was placed on a three-point fixture while the machine applied forces of varying degrees on the samples, this went on until the sample deflected. The flexural strength, maximum flexural stress, maximum strain and stress at a strain of the sample can be calculated from the data generated from this test.

Flexural Strength for Reinforced Composite

FT = Flexural strength

The flexural strength is calculated with the formula

$$FT = pl/bd^2 \quad (1)$$

Where P=maximum load applied, l = length of specimen, b=width of specimen and d=thickness

2.5 Hardness Test

There are several hardness tests. The Brinell hardness test was used to determine the hardness of the composite. ASTM B933-09 was used to carry out this test.

A sample with a length 5.6mm, width 19mm and thickness 3.2mm was loaded into the machine, and the steel ball under a load was forced on the surface of the sample, the indentation left on the sample after the force was measured and recorded as 1.75mm.

Hardness Value for Reinforced Composite

HBN = Brinell hardness number which is given by the formula (2)

Where p = constant axial force, N, D= Brinell bulb diameter, mm and d=depth of indentation 1.75mm.

Hardness Value of Composites

The hardness value of the composites was determined using the Brinell hardness number equation (3)

BHN = Brinell hardness number which is given by the formula (3)

Where P = constant axial force, D= Brinell bulb diameter and d=depth of indentation.

3. Results and Discussion

3.1 Flexural Test

Flexural strength is the ability of the composite material to withstand bending forces applied perpendicular to its longitudinal axis. The material could be used for cyclic loading applications hence the need for a flexural test. The values of the flexural test for the reinforced and unreinforced materials are shown in Table 1. The flexural strength of the polymer-composite reinforced with Nigerian long bamboo fibres decreased as the volume of fraction of the fibre was increased in the composite. This is as a result of the capability of bamboo fibre reinforced composite to support the stress transmitted from the polymer matrix.

Table 1: Flexural result for composite material under flexural loading

Reinforced composite		Unreinforced composite	
Applied Force(N)	Deflection (mm)	Applied Force(N)	Deflection (mm)
0.00	0.00	0.00	0.00
1.575	0.50	6.30	0.50
3.15	1.75	9.45	2.00
3.15	3.50	9.45	3.00
3.15	5.50	9.45	4.75
3.15	5.50	9.45	6.50

3.2 Hardness: Hardness test was carried out on reinforced and unreinforced material and the hardness value of the material determined using the Brinell Hardness Number (BHN).
The result of the hardness test for the composite and the unreinforced materials are shown in Table 2.

Table 2. Hardness result for reinforced and unreinforced material

Reinforced composite (BHN)	Unreinforced material (BHN)
433	348

4. Discussion of Results

4.1 Flexural Strength: Flexural strength test was carried out on the material to find out its ability to resist deformation under load. This test was carried out on both the developed reinforced material and the unreinforced material. In this test different magnitudes of forces were applied as shown in Table 1.0 with corresponding deflections or deformations. For the reinforced material, the maximum force which the material could withstand was 9.45N beyond which the material was completely deformed. The result also shows that even when the load was removed there was still further elongation of the material which showed plasticity of the material even though the composite was reinforced. Conversely, the reinforced material accommodated more load before it finally deformed compared to the unreinforced material.

4.2 Hardness Value: Hardness is a property of a material which measures its resistance to localised deformation in terms of penetration strength, indentation, scratching and abrasion. Hardness test is one of the best properties giving an indication of the material to resist indentation. Table 2 shows the information about the hardness test carried out on the developed reinforced material and the unreinforced material under investigation. The values obtained showed that the developed reinforced

material had a higher value than the unreinforced material. The value of the developed reinforced material was found to be 433 while that of the unreinforced material was 348.

5.0 Conclusion

Natural fibres, when used as reinforcement, compete with such conventional fibres as glass fibre. The advantages of the conventional fibres are good mechanical properties; which vary only a little, while their disadvantage is difficulty in recycling. Several natural fibre composites reach the mechanical properties of glass fibre composites, and they are already applied, e.g., in automobile and furniture industries. Till date, the most important natural fibres are Jute, flax, bamboo and coir. Natural Fibres are renewable raw materials and they are recyclable.

The tensile and flexural properties of epoxy (Bisphenol-A-di glycidyl ether-BADGE) composites reinforced with long bamboo fibre have been studied and discussed. The following conclusions can be drawn from the present research.

It has been noticed that the mechanical properties of the composites such as micro-hardness and flexural strength of the composites are also greatly influenced by the fibre fraction and type.

References

Ahmed, EM., Sahari, B. and Pedersen, P. 1999. The non-linear behaviour of unidirectional filament wound COTFRP, CFRP, and GFRP composites. Proceedings of World Engineering Congress, WEC 99, Mechanical and Manufacturing Engineering, Kuala Lumpur; 22-23 September, 1999 pp. 537–543.

Belmares, H., Barrera, A. and Monjaras, M. 1983. New composite materials from natural hard fibres. Part 2: Fatigue studies and a novel fatigue degradation model. Industrial & Engineering Chemistry Product Research and Development, 22(4):643-652

Casaurang, M., Herrera, P., Gonzalez, I. and Aguilar, VM. 1991. Physical and mechanical properties of henequen fibres. Journal of Applied Polymer Science, 43(3): 749-756.

Frederick, TW. and Norman, W. 2004. Natural fibres plastics and composites. 1st ed. New York: Kluwer Academic Publishers. pp. 400

Fuad, MYA., Rahmad, S. and Azlan, MRN. 1998. Filler content determination of bio-based thermoplastics composites by thermogravimetric analysis. Proceedings of the Fourth International Conference on Advances in Materials and Processing Technologies, 98, Kuala Lumpur, 24-28 August, 1998, pp. 268–275.

George, J., Sreekala, MS. and Thomas, S. 2001. A review on interface modification and characterization of natural fibre reinforced plastic composites. Polymer Engineering and Science, 41(9): 1471-1485.

Gowda, TM., Naidu, ACB. and Chhaya, R. 1999. Some Mechanical Properties of Untreated Jute Fabric-Reinforced Polyester Composites. Journal of Composites Part A: Applied Science and Manufacturing, 30(3): 277-284.

Holbery, J. and Houston, D. 2006. Natural-Fiber-Reinforced Polymer Composites in Automotive Applications, Journal of Materials (JOM), 58(11): 80-86.

Ichazo, MNC., Albano, J., González, R. and Perera, MV. 2001. Polypropylene/wood flour composites: treatments and properties. Composite Structures, 54(3): 207-214.

INBAR 2005. International Network for Bamboo and Rattan. Global forest resources assessment (FRA WP127) Working paper 127, Rome.

Joseph, K., Mattoso, LHC., Toledo, RD., Thomas, S., Carvalho, LH., Pothen, L., Kala, S. and James, B. 2000. Natural fibre reinforced thermoplastic composites. In Natural Polymers and Agrofibers Composites, ed. E. Frollini, A.L. Leão and L.H.C. Mattoso, San Carlos, Brazil: Embrapa. USP-IQSC, UNESP pp. 159-201.

Joseph, K. and Thomas, S. 1993. Dynamic mechanical properties of short sisal fiber reinforced low density polyethylene composites. Journal of Reinforced Plastics and Composites, 12(2): 139-155.

Joseph, K., Varghese, S., Kalaprasad, G., Thomas, S., Prasannakumari, L., Koshy, P. and Pavithran, C. 1996. Influence of interfacial adhesion on the mechanical properties and fracture behaviour of short sisal fibre reinforced polymer composites. European Polymer Journal, 32(2): 1243-1250.

Joseph, S., Sreekalab, MS., Oommena, Z., Koshyc, P. and Thomas, S. 2002. A comparison of the mechanical properties of phenol formaldehyde composites reinforced with banana fibres and glass fibres. Composite Science Technology. 62(14): 1857–1868.

Karnani, R. Krishnan, M. and Narayan, R. 1997. Bio-fibre-reinforced polypropylene composites Polymer Engineering and Science, 37 (2): 476-483.

Khalid, AA., Sahari, B. and Khalid, YA. 1998. Environmental Effects on the Progressive Crushing of Cotton and Glass Fibre/Epoxy Composite Cones. Proceedings of the Fourth International Conference on Advances in Materials and Processing Technologies, Kuala Lumpur; 24-28 August, 1998 pp. 680–689.

Luo, S. and Netravali, AN.1999. Mechanical and thermal properties of environmentally friendly green composites made from pineapple leaf fibres and poly (hydroxybutyrate-co-valerate) resin. Polymer Composites, 20(3): 367-378.

Lundquist, L., Marque, B., Hagstrand, PO., Leterrier, Y. and Månson, JAE. 2003. Novel Pulp Fiber Reinforced Thermoplastic Composites. Composites Science and Technology, 63(1): 137-152.

Mansur, MA. and Aziz, MA. 1983. Study of Bamboo-Mesh Reinforced Cement Composites. International Cement Composites and Lightweight Concrete, 5(3):165-171.

Mishra, S., Misra, M., Tripathy, SS., Nayak, SK. and Mohanty, AK. 2002. The influence of chemical surface modification on the performance of visa polyester biocomposites. Polymer Composites 23(2):164-170.

Satyanarayana, KG., Sukumaran, K., Mukherjee, PS., Pavithran, C. and Pillai, SGK. 1990. Natural Fiber-Polymer Composites. Journal of Cement and Concrete Composites. 12(2): 117-136.

Schneider, JP. and Karmakar, AC. 1996. Mechanical performance of short jute fibre-reinforced polypropylene, Journal of Materials Science Letters, 15: , 1996, pp. 201-202.

Sreekala, MS., Kumaran, MG., Joseph, S., Jacob, M. and Thomas, S. 2000. Oil palm fibre-reinforced phenol formaldehyde composites: influence of fibre surface modifications on the mechanical performance. Applied Composite Materials, 7(3): 295-329.

Tavman, IH. 1997. Thermal and mechanical properties of copper powder filled poly (ethylene) composites. Powder Technology, 91(2): 63–67.

Valadez-Gonzales, A., Cervantes-Uc, JM., Olayo, R. and Herrera Franco, PJ. 1999. Effect of fibre surface treatment on the fibre-matrix bond strength of natural fibre reinforced composites. Composites, Part B 30 (3): 309–320.

Van de Velde, K. and Kiekens, P. 2002. Thermal degradation of flax: The determination of kinetic parameters with thermogravimetric analysis. Journal of Applied Polymer Science, 83(12): 2634-2643.

Yamamoto, I., Higashihara, T. and Kobayashi, T. 2003. Effect of silica particle characteristics on impact/usual fatigue properties and evaluation of mechanical characteristics of silica-particle epoxy resins. JSME International Journal-Series A: Solid Mechanics and Material Engineering, 46 (2): 145-153.